Wave Induced Bubble Clouds and their Effect on Radiance in the Upper Ocean

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LONG-TERM GOALS

A goal of this project is to measure wave induced bubble clouds and their effect on radiance in the upper ocean and to address the fact that despite the fundamental importance of optical backscatter in the ocean it is still not possible to explain more than 5 to 10 percent of the particulate backscattering in the ocean based on known constituents even during periods with no active wave breaking. We want to investigate the role of upper ocean bubbles in these processes. In this project we are working closely with Svein Vagle (IOS).

OBJECTIVES

During this project, which is a component of the much larger RadyO project, we are addressing the following scientific questions:

- How does radiant light fluctuate beneath a sea in which waves are breaking?
- Can this variability be explained in terms of measured bubble populations with wave scattering models using Mei theory as a kernel for light-bubble interactions?
- Can a predictive model be developed for radiant light that includes wave conditions and predicted subsurface bubble injections?

The presence of surfactants on the surface of the bubbles decreases their buoyancy and therefore their rise speed. The presence of compounds on the bubbles will also modify their dissolution rate and will therefore change the dynamics of the temporal and spatial evolution of bubble clouds and their size

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distributions. Bubbles are effective at scattering light; thus a proper understanding of the role of surfactants on the bubble field is important to understanding observed radiance modulations.

With our collaborators at IOS and the larger RaDyO group of investigators, we measure and model bubble injection and radiance fluctuations in the upper ocean during wave-breaking conditions. The critical measurements of bubble size distributions and the way in which these size distributions evolve with time after wave breaking are carried out using acoustical resonators. High air fractions lying beyond the resonator measurement range are monitored with electrical conductivity cells. The surface wave field is measured with an array of Doppler sonars. The radiance distribution is measured on meter length scales in the top 10 m of the ocean by other RadyO participants. The bubble clouds are further characterized with optical systems and sonars.

To improve our understanding of the role of the microlayer and the microlayer surfactants the IOS team is gathering surfactant data. This information is incorporated in models of bubble rise and dissolution rate, so that we can better estimate bubble populations and hence their contribution to optical scattering.

APPROACH

The instruments and technology for carrying out this work have been developed collaboratively by the PI and his collaborator Svein Vagle (IOS) and as part of a program to study the role of the microlayer in air-sea gas exchange processes. This instrumentation has been modified to suit the specific requirements of the RaDyO field campaigns. A further development of the resonator concept, in which the acoutical frequency range has been extended to 1 MHz was implemented so as to detect the contribution bubbles with radius < 10 μm.

During 2009 we:

1. Participated in a field study in Santa Barbara Channel.

2. Participated in the development and testing of inversion approaches that can be applied to acoustical resonators to recover bubble distributions, determining the limits of performance of the instrument, especially at the higher frequencies where contributions from smaller bubbles can be detected.

3. Tested the operation of a new version of the acoustical resonator designed to operate at significantly higher frequencies than previously used (see Fig. 1).

4. Prepared for and participating in a field experiment in Hawaii involving R/V FLIP and R/V KILO MOANA. The experiments involved deploying the resonators, along with acoustic sonars and in conjunction with optical sensors deployed by other RaDyO participants. Instrumentation was deployed from both vessels.

WORK COMPLETED

A new inversion algorithm was developed and tested. A new resonator developed at the Institute of Ocean Sciences implemented and tested. We participated in the Hawaii RaDyO cruise and collected data from both the R/V FLIP and R/V KILO MOANA.

Figure 1: Redesigned resonator designed to operate at frequencies up to 1 MHz attached to the MASCOT package for deployment from R/V Kilo Moana on the Hawaii cruise.

RESULTS

Separation of geometrical and resonant bubble scattering effects on attenuation was investigated. Everal techniques were evaluated and an inversion algorithm developed which produces stable results, and which sets uncertainty limits on the inversion procedure. The better the knowledge of the larger bubble population, the better this algorithm can perform. Geometric bubble scattering will not affect the population measurement of smaller bubbles unless the bubble population distribution slope is less than -2. Resonator calibration tests were conducted to determine the effect of temperature variations on resonator performance. It was determined that resonator spectral peak shifts due to changes in the sound speed, associated with bubble effects, could provide more robust data for inversion to recover bubble populations. Examples of data inversion are shown in Figs. 2 and 3.

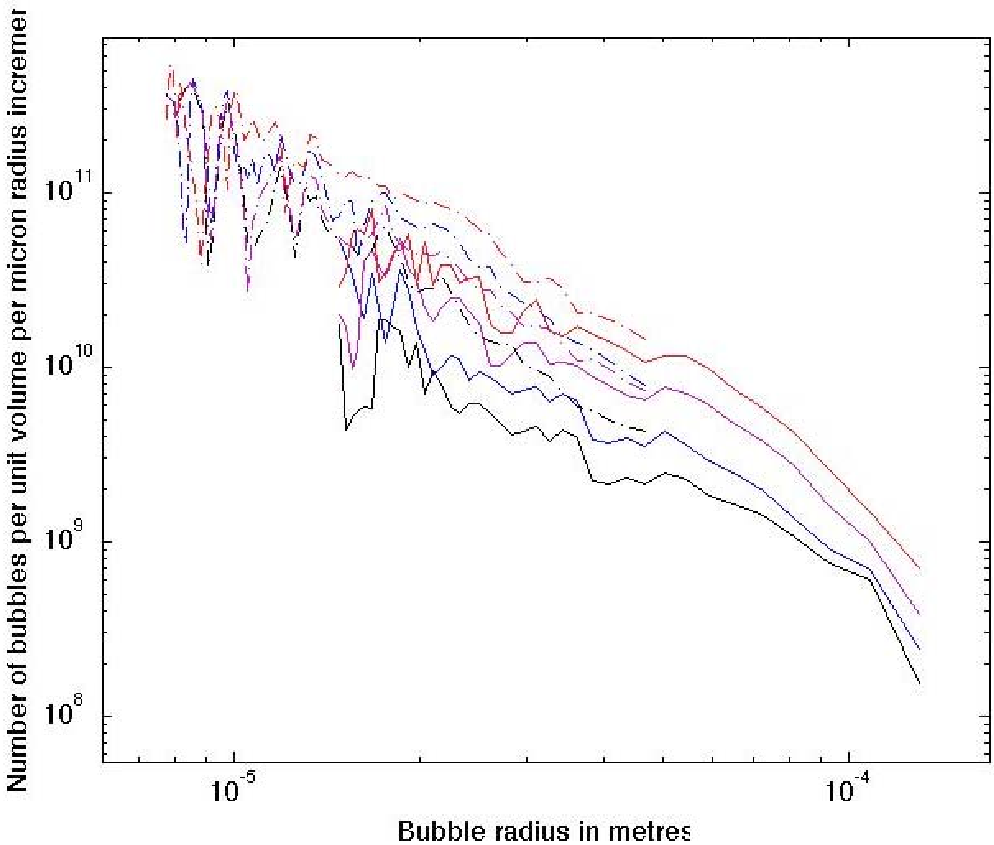

Figure 2: Bubble size spectra expressed as number of bubbles per unit volume per micron radius increment as a function of bubble radius in meters. The data were acquired using two resonators deployed from FLIP. The two resonators deployed from the Kilo Moana complemented each other because one had high quality factor peaks from 20-200 kHz and the other had high quality factor peaks from 60-400 kHz. They were deployed next to each other to extend the range of measurement at a single time. The figure shows a set of 4 samples from each instrument (solid and dashed curves) during a variation in bubble density. The major complexities of the spectra are the gradual increase in trough level with frequency, and the more complicated peak shapes. The smallest detectable bubble radius depends on bubble density, with decreasing radius being detectable at higher concentrations.

Fig. 2 shows four consecutive measurements from the resonators on FLIP, acquired on the Hawaii cruise. There is one measurement every second, but here we only show four bubble populations with a 3 second spacing. The sequence is black, blue, purple and then red and solid lines show results from one resonator while dashed lines show the results from the other. Preliminary data from each resonator are only shown over the spectral range which included high quality factor peaks. They agree qualitatively in the overlap region. These data will be further analysed to remove electrical noise from nearby instruments and to take full account of the detailed spectral shape, so we anticipate that these curves will be much smoother after a full analysis.

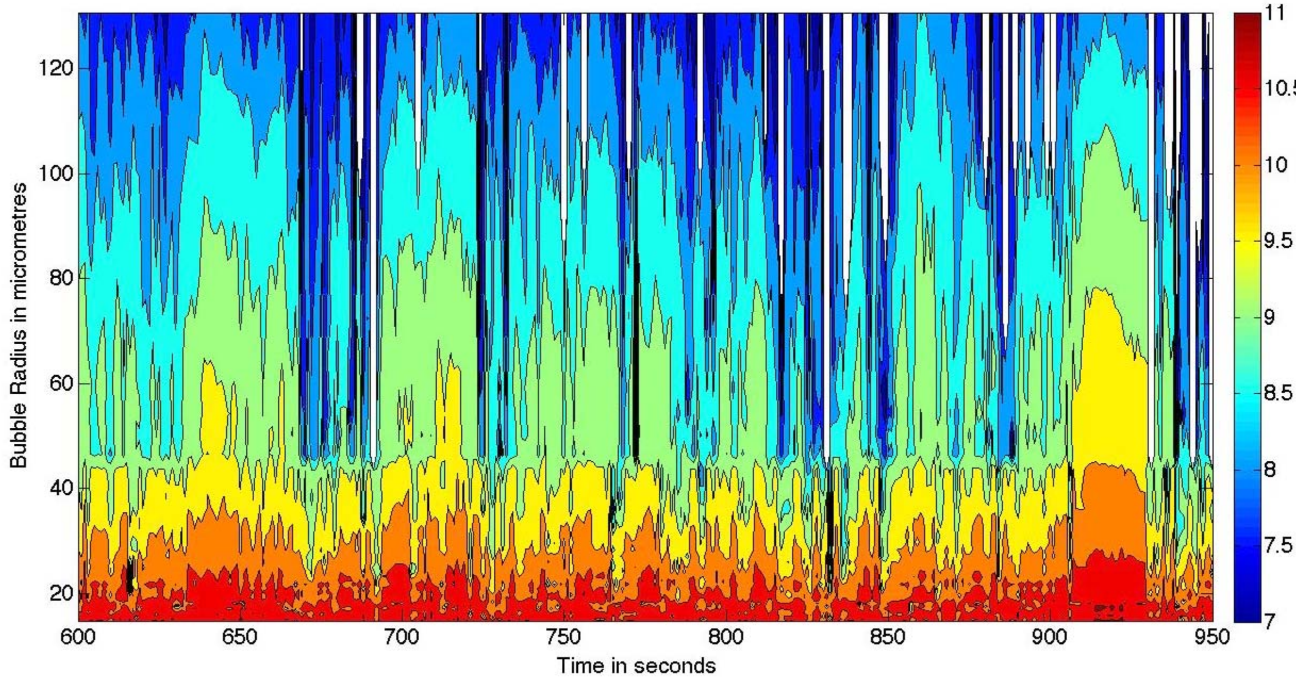

Figure 3. Color contour display of bubble size spectra over a 350s period, showing variability due to breaking waves measured on September 3rd during the relatively brief period when the wind speed was sufficient to cause breaking events. The contour labels are powers of ten in bubble number - so the label 9 represents 10^9 bubbles per unit volume per micron radius increment. This figure combines preliminary data from two resonators, and includes bubble radii from 15 microns to 130 microns. The bubble population distribution slope is approximately -3 throughout.

RELATED PROJECTS

The bubble sensing technology being explored in this project is directly relevant to work being carried out in an acoustic communications project N000140210682 and associated MURI project.